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Forecasting Research

Forecasting Research Division
Technical Report No. 130

Summary Report on the Tests of the Automated Cloud Extrapolation Forecast for Nimrod

by

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31 October 1994

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1 Introduction

There is a Nimrod system requirement for forecasts for up to six hours ahead of cloud amount in a number of atmospheric layers together with related products such as cloud base and cloud top heights. Cloud amount forecasts will be generated by a combined technique which merges the products of a sequence of hourly extrapolation forecasts together with mesoscale model fields. The two methods will be merged in such a way that the extrapolation technique will dominate near the beginning of the forecast period, while the model will assume increasing importance at longer lead times. This report describes the performance of the extrapolation component of the cloud forecast in selected case studies.

The extrapolation forecast concentrates solely on predicting the movement of cloud within a level; no attempt is made to account for the development or decay of cloud by considering vertical motions, or model precipitation processes. Performance targets for the extrapolation forecast are specified in the Nimrod Stage 4 workplan, which states that the one hour forecast should achieve a Hit Rate (HR) of 70% and a False Alarm Rate (FAR) of 30%. The targets for the full (merged) cloud forecast are defined in the Nimrod User Requirement.

2 The Extrapolation Forecast Method

2.1 The cloud analysis

The extrapolation forecast depends on an accurate, up to date description of the initial cloud field. The MOPS (Moisture Observation Pre-processing System) cloud analysis is used in the initialisation of the mesoscale model and consists of cloud amount on model levels and at a horizontal resolution of 15km. MOPS uses synoptic observations of both cloud and precipitation together with radar data and satellite infrared data to construct its analysis. The scheme starts with a first guess taken from a three hour mesoscale model forecast, which is then modified giving priority to the current data where they are available and using the first guess elsewhere. The scheme maintains consistency between the presence of cloud and precipitation and produces a surface precipitation analysis in addition to the three dimensional cloud analysis. A full description of MOPS is given by Wright (1993). Prior to performing the extrapolation forecast the MOPS cloud is interpolated onto horizontal levels - this is done to prevent cloud from changing its height above sea level during the forecast, which would happen if it was forced to move along model levels.

2.2 Motion analysis

The extrapolation forecast predicts only the movement of cloud, hence the essence of the problem is to recognise areas of cloud in the analysis and to deduce the most appropriate velocity vectors to apply to them. The method applies rainfall velocity fields to precipitating cloud and moves non-precipitating cloud with model winds which are interpolated to the same horizontal levels. This approach maintains consistency between different Nimrod products

by preventing deep cloud and precipitation from becoming separated in the course of the forecast while allowing unconnected layers of shallow cloud to move independently.

The rainfall velocity fields used to extrapolate the movement of precipitating cloud are the same as those used to advect radar data in the Nimrod precipitation extrapolation forecast (Conway, Ryall and Thomas, 1993). They are found by examining two radar pictures which are closely spaced in time. Rainfall 'objects' are identified in the later picture by examining the distribution of radar echoes, those echoes which are found to be separated by less than a predefined distance are assigned to the same object. A rainfall object which contains at least a hundred and fifty pixels is classified as 'large', those containing fewer pixels are 'small'. The earlier of the two radar maps is moved as a whole using a single vector and the resulting picture correlated in turn with each large object in the second map. This process is repeated for a range of vectors to determine which gives the maximum correlation for each object. The earlier picture is also moved with mesoscale model forecast wind fields taken from different times and levels; again, in each case the result is compared with the large objects to determine the correlation between the two. The velocity which produces the highest correlation for each rainfall object, whether a single vector or a model wind field, is selected and applied to produce the precipitation forecast. Small objects are assigned the same velocity field as the nearest large object. The motion analysis software also segments the entire radar field by 'growing' all the objects until they touch and every pixel is assigned a value. For the purpose of producing the cloud forecast it was necessary to extend the segment map beyond the edges of the radar area in order that every model gridpoint could be associated with a precipitation object. The extension was achieved by allowing the growth of the objects to continue until they reached the boundaries of the model area.

2.3 The cloud forecast

A number of approaches to producing the extrapolation forecast were discussed by Pamment and Conway (1994) and the following method was recommended. Once appropriate velocity fields have been determined for the precipitating cloud the main task is to identify the precipitating and non-precipitating cloud regions. This is achieved by referring to the MOPS precipitation analysis to produce a three dimensional cloud mask. In grid squares where MOPS has analysed no precipitation the cloud is treated as non-precipitating at all levels; in grid squares with precipitation, all cloud below the -15^{o}C isotherm is treated as precipitating and above the isotherm cloud at successively higher levels is treated as precipitating until two successive clear layers are encountered. All cloud above the two clear levels is treated as non-precipitating. This method of identifying precipitating cloud is consistent with the structure of the MOPS analysis (Wright, 1993). When cloud has been identified as either precipitating or non-precipitating in the analysis it continues to be classified in the same way throughout the forecast.

The forecast treats the cloud one level at a time and does not allow cloud to move between levels. Precipitating cloud is moved with the velocity field which was found to be the most appropriate in the motion analysis stage, non-precipitating cloud is moved with the mesoscale

model forecast wind for the correct grid square and level. Advected cloud rarely lands precisely within the boundaries of a single grid square, so the cloud fraction is shared between the four grid squares closest to the exact forecast position, weighted according to the amount of overlap with the advected square. When cloud from more than one initial position coincides in a single grid square the contributions from all the advected cloud are summed. The summed cloud fraction is not allowed to exceed the maximum value present in all the contributing grid squares at the time of analysis.

3 Evaluation of the Extrapolation Forecast

Cloud forecasts for selected case studies were assessed against analyses which were produced by performing hourly runs of MOPS. Both the forecast and analysis for each time were divided into three height bands of cloud below 1000 feet above sea level, cloud below 5000 feet above sea level and total cloud. Cloud was assigned to the three layers by choosing the maximum cloud fraction from all the levels which overlapped a particular band, that is, using the maximum overlap method. The forecast and analysis in each height band were thresholded at 4 oktas, then smoothed using a Gaussian function with a half width of 25km at half height as described in the Nimrod User Requirement. The Gaussian smoothing was the same as that used in the assessment of the Nimrod rainfall forecast described by Thomas, Conway and Golding (1993) who also discuss the effect of varying the half width.

Objective assessment of the forecast scheme was done by calculating Hit Rate (HR) and False Alarm Rate (FAR) for the thresholded and smoothed cloud fields. The objective assessment was only perfomed inside the area of radar data coverage at each time because the hourly MOPS analyses may be less reliable outside that region. This is not a shortcoming of the MOPS scheme, but rather of the method used for producing the analyses in the case studies presented here. When running operationally the model fields which MOPS uses as its first guess are taken from forecasts with lead times of three hours, however, the analyses which were produced for this assessment used first guess fields from model reruns having lead times of up to eighteen hours. The effect of using older background fields in MOPS is likely to be greatest in the precipitation analysis: inside the radar area the observed data almost entirely replace the first guess, but beyond the radar range the background field is modified only by synoptic reports. MOPS maintains consistency between its precipitation and cloud analyses, hence an inaccurate rainfall field could have an adverse effect on the cloud. For this reason it was decided to restrict the calculation of objective scores to those grid squares where radar data were present. Table 1 lists the cases used in the assessment.

Table 1. List of case studies

Date	Analysis time(s)	Description
02 November 1993	10z	Stratocumulus sheet
29 November 1993	04z, 14z	Active cold front
07 December 1993	04z	Waving cold front
16 January 1994	04z, 14z	Convection in northerly flow
25 January 1994	08z, 16z	Organised convection

4 Results

4.1 Objective assessment

Table 2 gives the scores for lead times of one, two and three hours for the eight forecast runs. For four of the runs scores are presented for the 5000 feet and total cloud categories only because those cases contained very little forecast or analysed cloud below 1000 feet and it was not possible to calculate meaningful statistics. Additional cases which contain significant amounts of cloud below 1000 feet will be sought and used in the testing of the full merged forecast.

The Nimrod User Requirement stipulates that for the final merged forecast cloud in all three height bands should achieve a HR of greater than 0.7 at T+1 and greater than 0.6 at T+3 with corresponding FAR scores of less than 0.3 and less than 0.5. The scores averaged over all the runs meet the Nimrod User Requirement in all height bands.

4.2 Subjective assessment

Figures 1 to 9 show the T+1 and T+3 forecasts from each of the runs compared with the corresponding MOPS analyses. Also shown (in the top two frames) are the METEOSAT infrared image and the corresponding MOPS picture at the analysis time for each run. The middle two frames of each figure show MOPS and the extrapolation forecast at T+1 while the bottom two frames show the T+3 fields. The heights of the cloud in the MOPS and forecast data were converted to temperatures by assuming the presence of an ICAO standard atmosphere and the processed fields were displayed as pseudo-infrared images, thus the whitest cloud is the coldest (highest) and the darkest cloud is the warmest (lowest). A threshold of 2 oktas was applied to the cloud data before displaying it. The pseudo-infrared images therefore show the highest cloud of greater than 2 oktas that was present in each grid square. Areas of pure black in the forecast images indicate missing data and are caused by the lack of cloud information beyond the model boundary which means that some grid squares are left empty as cloud moves away during the forecast. In the merged forecast these missing data areas could be filled using mesoscale model cloud.

4.2.1 DT 10z 02/11/93

See Fig. 1. A stratocumulus sheet covered most of the model area and a front was approaching from the south. The distribution of both the stratocumulus and the frontal cloud was well forecast at T+1. Apart from some of the thicker frontal cloud at the western end of the English Channel there was no precipitation at the analysis time, so the forecast was produced almost entirely using mesoscale model winds which were light and from the south at the levels which contained most of the cloud. At T+3 the position of the frontal cloud is again well forecast.

4.2.2 DT 04z 29/11/93

See Fig. 2. An active frontal system was approaching the British Isles from the west at the time of the analysis. At T+1 a gap has appeared in the high cloud to the west of Ireland - the cause of this is the distribution of precipitation in the analysis, shown in Fig. 3. Cloud at the extreme western edge of the model area is identified as precipitating and is consequently moved with a single vector which was determined from the analysis of rainfall movement inside the radar area. The majority of the frontal cloud is ahead of the surface precipitation and is therefore identified as non-precipitating and moved with the model wind field at the appropriate levels. This has caused the cloud to part along the boundary of the surface precipitation. Some evidence of vertical shear in the model winds is also evident in that the trailing edge of the highest cloud is slightly ahead of the edge of the layer beneath it. In spite of the split west of Ireland the T+1 image gives a good general indication of the position of the frontal cloud and the distribution of the remaining cloud is well forecast. At T+3 the separation between the precipitating and non-precipitating cloud has increased and the effects of vertical wind shear are more pronounced.

The major error at T+1 in this case is the separation of the precipitating and non-precipitating cloud which was caused by applying an inappropriate vector to the precipitating region. A possible solution would be to take the motion analysis technique used for radar data and apply it to two consecutive MOPS precipitation analyses, thus determining separate velocity vectors for precipitation objects which fall outside the radar area. This would prevent unconnected objects being assigned the same velocity simply because they happen to fall inside the same extended precipitation segment. Precipitating cloud which is analysed inside the radar area should be moved with the velocities determined from the motion analysis of the radar data in order to maintain consistency between the Nimrod rain and cloud forecasts. However, precipitating cloud which is analysed outside the radar area should be moved with the velocities determined from the MOPS analyses.

4.2.3 DT 14z 29/11/93

See Fig. 4. By 14z the frontal system had progressed eastwards and the main rain band was affecting Ireland and the Irish Sea and at T+1 the frontal cloud is well forecast. A small separation is discernible between regions of precipitating and non-precipitating cloud along the coasts of Scotland and NW England. However, the separation is much less pronounced than in the 04z run, probably because the velocity of the precipitating cloud could be determined directly from radar rainfall data rather than simply being inferred from the image

segmentation. At T+3 the cloud separation is more obvious, but again is less pronounced than in the earlier run.

4.2.4 DT 04z 07/12/93

See Fig. 5. A waving cold front was moving southeastwards over southeast England and France. Showers were affecting northern and western areas. At T+1 both the frontal and convective cloud are well forecast. At T+3 the cloud distribution is again well forecast, though some narrowing of the highest cloud has occurred.

4.2.5 DT 04z 16/01/94

See Fig. 6. Most of the model area was affected by broken cloud which formed in a northerly airstream. A band of higher cloud was present over southern England and France. Precipitation was confined to scattered showers on north facing coasts. At T+1 the cloud distribution is well forecast, gaps in the cloud over Ireland and southwest Scotland show good agreement between the forecast and the MOPS analysis. Gaps analysed near the Welsh border and East Anglia are also present in the forecast, though slightly misplaced. At T+3 the forecast high cloud in the Channel extends too far to the west because the cloud in the region has decayed and the extrapolation forecast has no mechanism to account for this. The forecast has also caused the gap in the cloud over Ireland to become elongated.

4.2.6 DT 14z 16/01/94

See Fig. 7. An area of high cloud is approaching from the northwest associated with a low centre to the north of Scotland. Most of Britain continues to be affected by patchy medium level cloud. At T+1 the effect of vertical wind shear can be seen in the high cloud to the northwest where the trailing edges of the cloud layers have beome separated. This whole region of cloud is also slightly too far to the southeast compared with the MOPS analysis. The small patch of high cloud southwest of the Scilly Isles in the T+1 image appears to have originated south of Ireland in the 14z analysis. The presence of this high cloud at 14z is not consistent with the METEOSAT image and may have appeared as a result of a single synoptic report. The forecast has exaggerated the extent of the gap in the cloud to the south of Ireland and has also extended the gap over Wales too far east. At T+3 the high cloud has moved well ahead of its analysed position and the shearing between the layers has become more apparent.

The tendency of non-precipitating cloud layers to separate in regions of large vertical wind shear will need to be addressed by the merged cloud forecast, perhaps by limiting the distance that high cloud in these regions is allowed to move ahead of the corresponding model cloud, or perhaps by simply substituting the model high cloud.

4.2.7 DT 08z 25/01/94

See Fig. 8. A cold front crossed the British Isles from west to east during the early morning and was followed by widespread showers which became organised into bands. At T+1 the position of the main frontal band is well forecast. The forecast has failed to produce a gap in the cloud in eastern Scotland and has placed the gap near Ireland too far to the north, but

nevertheless gives reasonable guidance as to the areas where breaks in the cloud could be expected. At T+3 the main areas of frontal and convective cloud are correctly positioned but the extrapolation forecast does not reproduce the clearing of cloud from northern England and the Midlands.

4.2.8 DT 16z 25/01/94

See Fig. 9. At T+1 the position of the higher cloud is generally well forecast. Breaks in the cloud are exaggerated in size but are in the correct positions. At T+3 the convective cloud is more broken in appearance, the forecast has placed some higher cloud over northern England and Scotland which does not appear in the MOPS analysis.

5 Conclusions and Recommendations

1. A method of producing cloud extrapolation forecasts for Nimrod has been described. The full Nimrod cloud forecast will consist of a merged product containing contributions from both the extrapolation component and the mesoscale model.

2. Eight runs taken from five case studies have been performed and assessed against the standards laid down in the Nimrod User Requirement. Cloud was assessed in three height bands: below 1000 feet above mean sea level, below 5000 feet above mean sea level and total cloud.

3. The cloud forecast when averaged over all the runs satisfies the Nimrod User Requirement for all three height bands at T+1 and T+3. The User Requirement is satisfied by every individual run in the 5000 feet and total cloud bands. Three of the four runs which contain significant amounts of cloud below 1000 feet also individually satisfy the User Requirement.

4. In two of the runs (29/11/93) separation occurs between precipitating and non-precipitating cloud. A method of reducing this effect by carrying out motion analysis of MOPS precipitation and applying the resulting velocities to precipitating cloud outside the radar area is recommended.

6. Strong vertical wind shear sometimes causes high cloud layers to become separated during the forecast. It is recommended that this problem be addressed in the merged forecast by preventing high cloud from moving more than some limiting distance from the model cloud in regions of strong shear, or by replacing extrapolated cloud with model cloud.

7. Grid squares in which the extrapolation forecast is unable to predict cloud because of the lack of data beyond the model boundary should be filled with mesoscale model cloud in the merged forecast.

6 References

Conway, B.J., Ryall, G. and Thomas, N. (1993) "Summary Report on Tests of the Automated Rainfall Extrapolation/Advection Scheme for Nimrod." *Nowcasting Development Group Working Paper No. 64.*

Pamment, J.A. and Conway, B.J. (1994) "A Proposed Techniqe for Producing Cloud Extrapolation Forecasts for Nimrod. Version 1.01." *Nowcasting Development Group Working Paper No. 81.*

Thomas, N., Conway, B.J. and Golding, B.W. (1993) "Summary Report on the Enhancements and Tests of the Automated Rainfall Extrapolation/Advection Scheme for Nimrod. Version 1.1." *Nowcasting Development Group Working Paper No. 75.*

Wright, B.J. (1993) "The Moisture Observation Pre-processing System (MOPS)." *Forecasting Research Division Technical Report No. 38.*

Table 2. Objective scores obtained in the test runs

Analysis Time		T + 1		T + 2		T + 3	
		HR	FAR	HR	FAR	HR	FAR
10z 02/11/93	< 1000'	0.61	0.02	0.41	0.15	0.57	0.05
	< 5000'	0.95	0.01	0.94	0.02	0.94	0.03
	Total	1.00	0.00	1.00	0.00	1.00	0.00
04z 29/11/93	< 1000'	0.82	0.04	0.77	0.17	0.72	0.29
	< 5000'	0.84	0.01	0.88	0.00	0.82	0.01
	Total	0.92	0.01	0.97	0.00	0.88	0.00
14z 29/11/93	< 1000'	0.79	0.16	0.88	0.22	0.83	0.49
	< 5000'	0.86	0.01	0.92	0.08	0.90	0.11
	Total	0.97	0.00	0.97	0.00	0.97	0.02
04z 07/12/93	< 5000'	0.93	0.03	0.89	0.13	0.83	0.13
	Total	1.00	0.00	0.99	0.04	0.99	0.02
04z 16/01/94	< 5000'	0.96	0.07	0.98	0.16	0.94	0.12
	Total	0.94	0.02	0.95	0.09	0.90	0.04
14z 16/01/94	< 5000'	0.77	0.03	0.73	0.07	0.67	0.07
	Total	0.95	0.03	0.92	0.07	0.88	0.06
08z 25/01/94	< 1000'	0.84	0.14	0.73	0.27	0.71	0.45
	< 5000'	0.88	0.09	0.94	0.14	0.91	0.13
	Total	0.95	0.11	0.95	0.14	0.94	0.15
16z 25/01/94	< 5000'	0.93	0.00	0.88	0.01	0.87	0.03
	Total	0.95	0.00	0.92	0.00	0.89	0.01
Mean over 4 runs	< 1000'	0.77	0.09	0.70	0.20	0.71	0.32
Mean over 8 runs	< 5000'	0.89	0.03	0.90	0.08	0.86	0.08
	Total	0.96	0.02	0.96	0.04	0.93	0.04

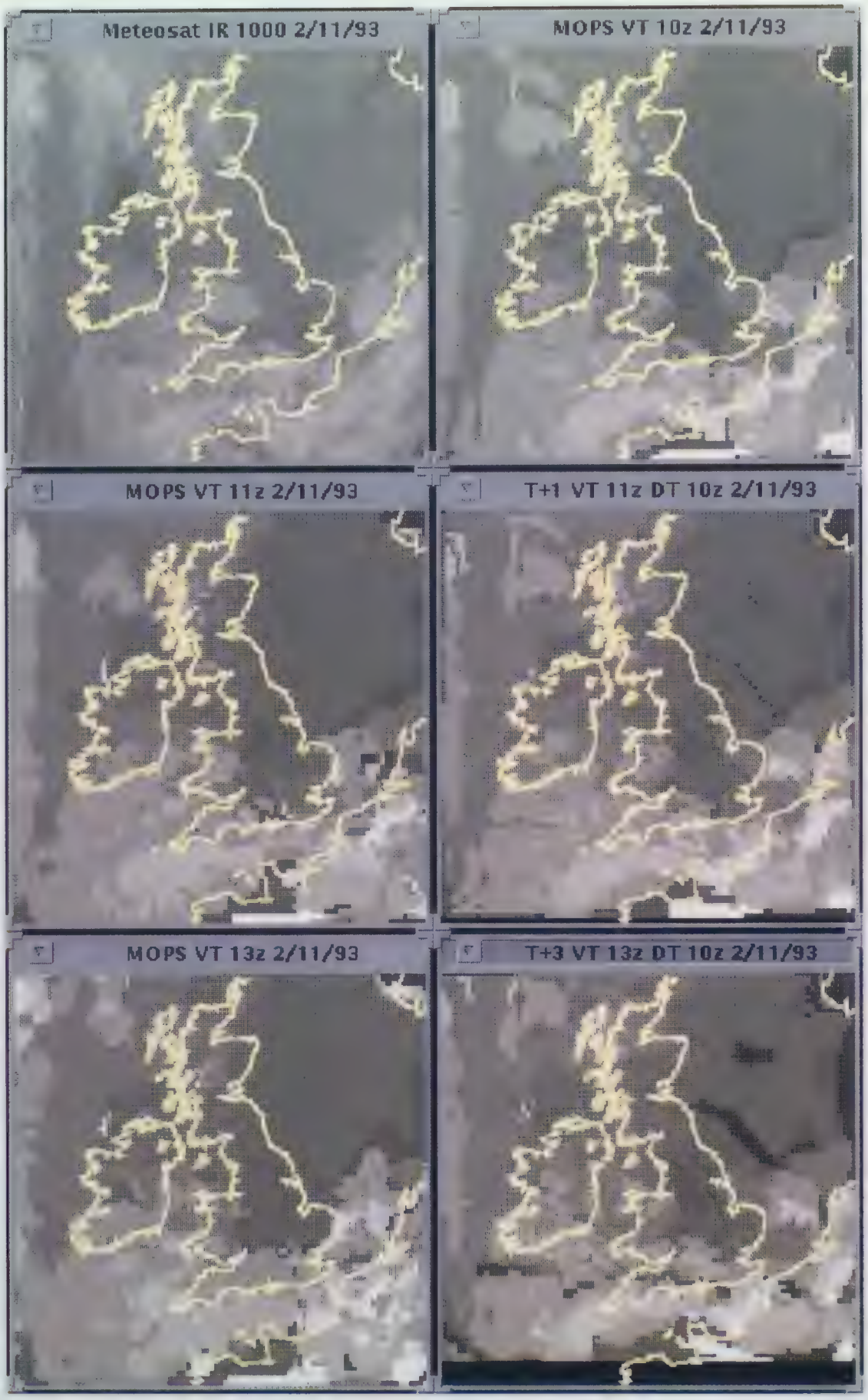
Meteosat IR 1000 2/11/93
MOPS VT 10z 2/11/93
MOPS VT 11z 2/11/93
T+1 VT 11z DT 10z 2/11/93
MOPS VT 13z 2/11/93
T+3 VT 13z DT 10z 2/11/93

Figure 1

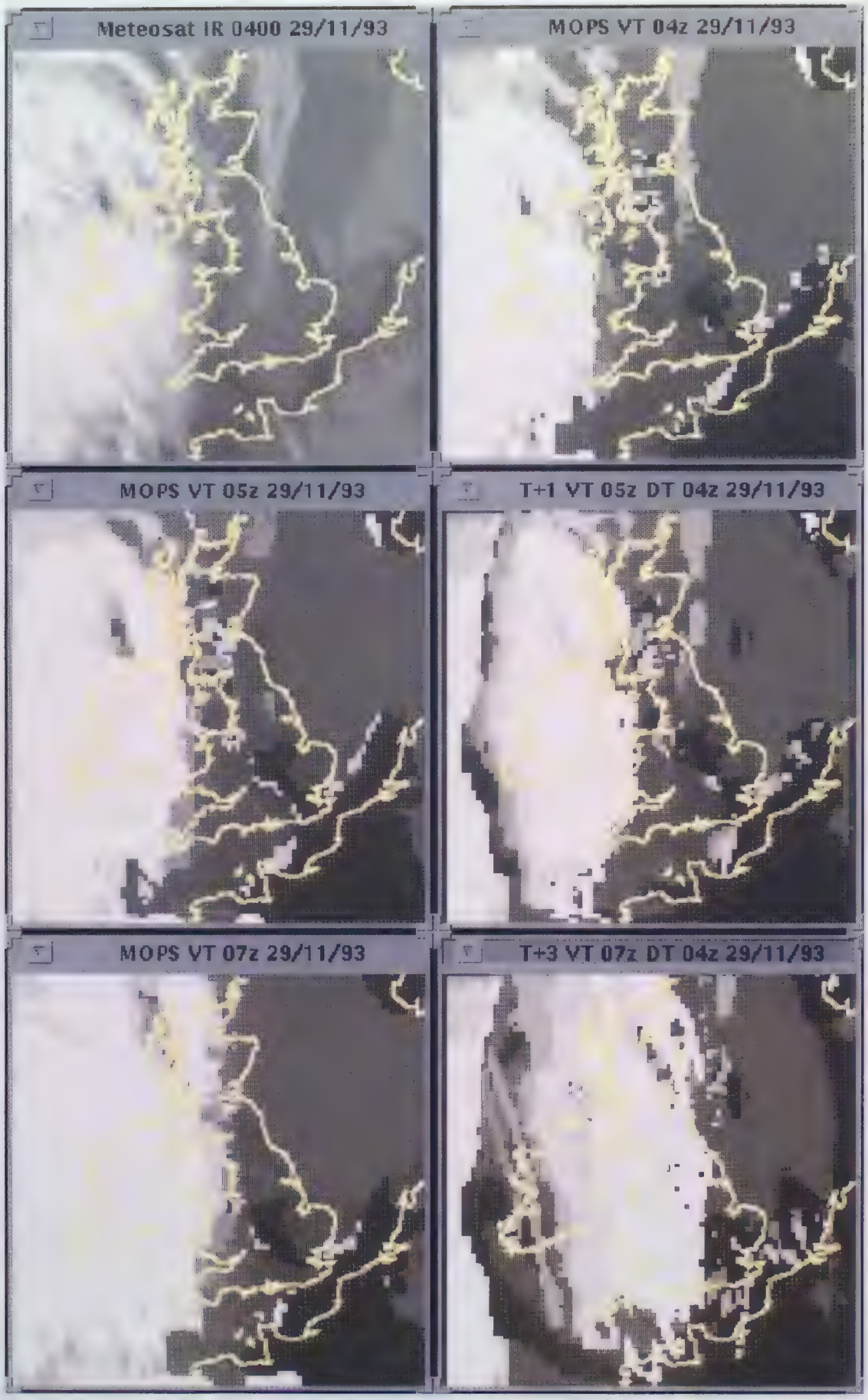
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Figure 2

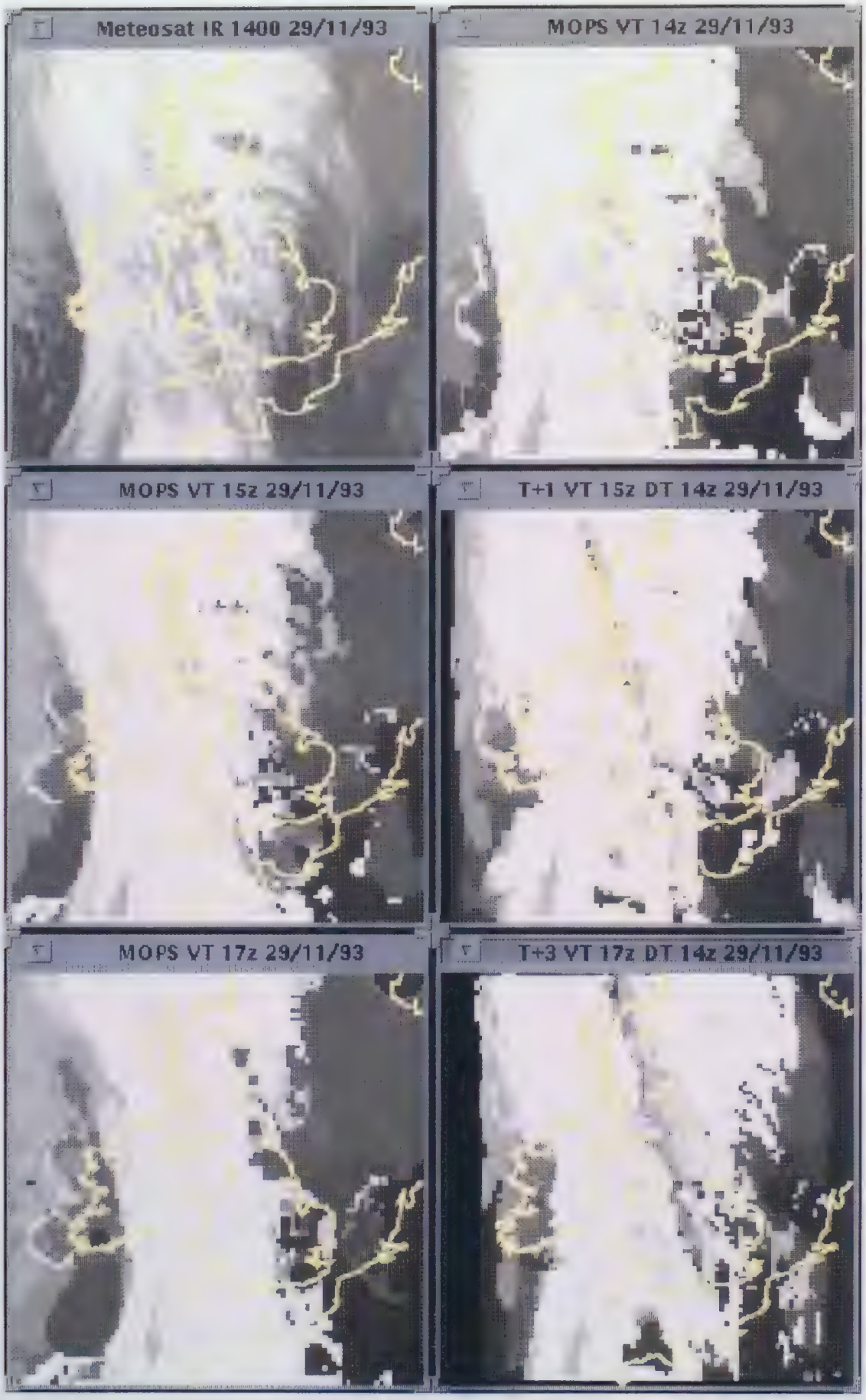
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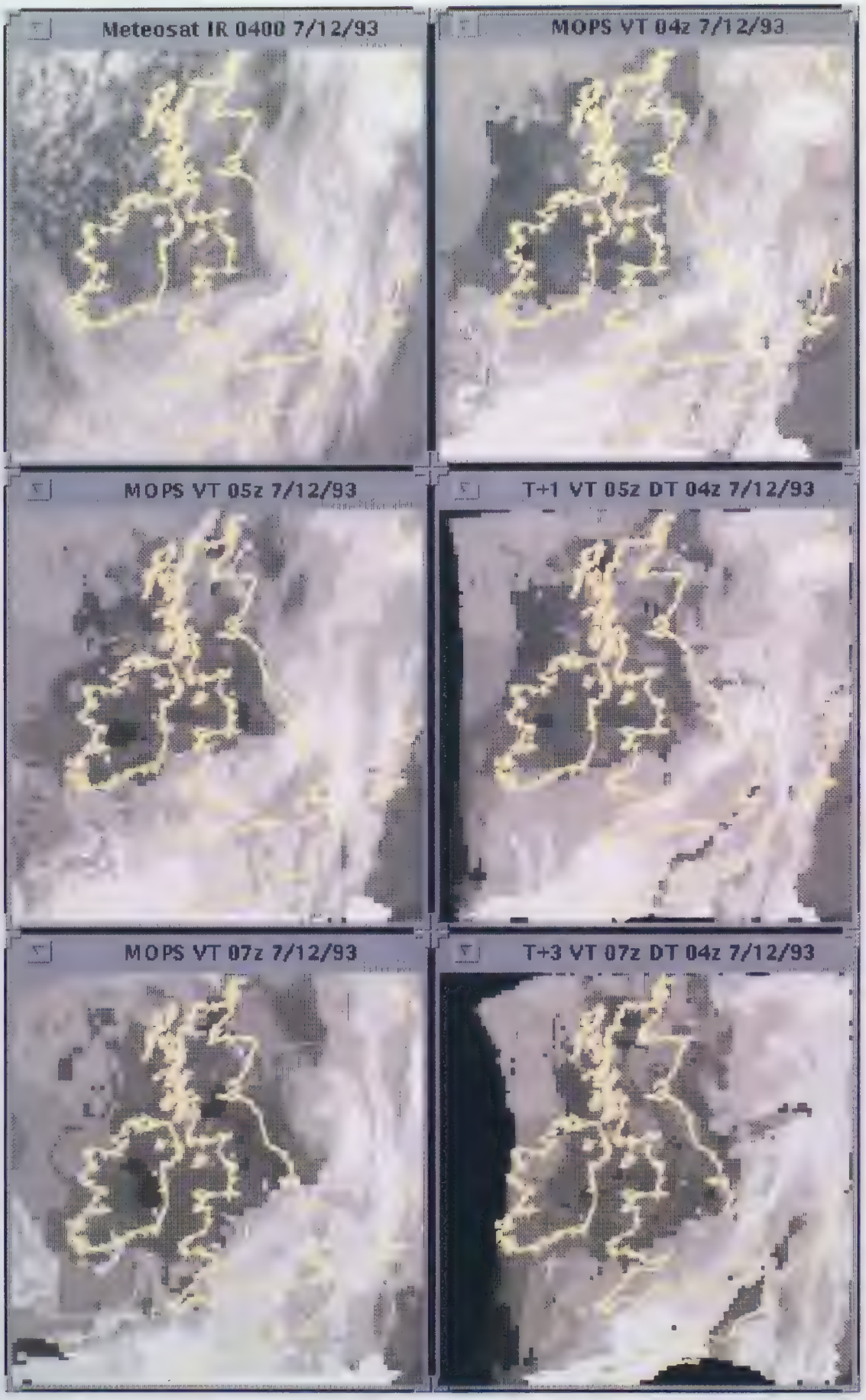
Figure 4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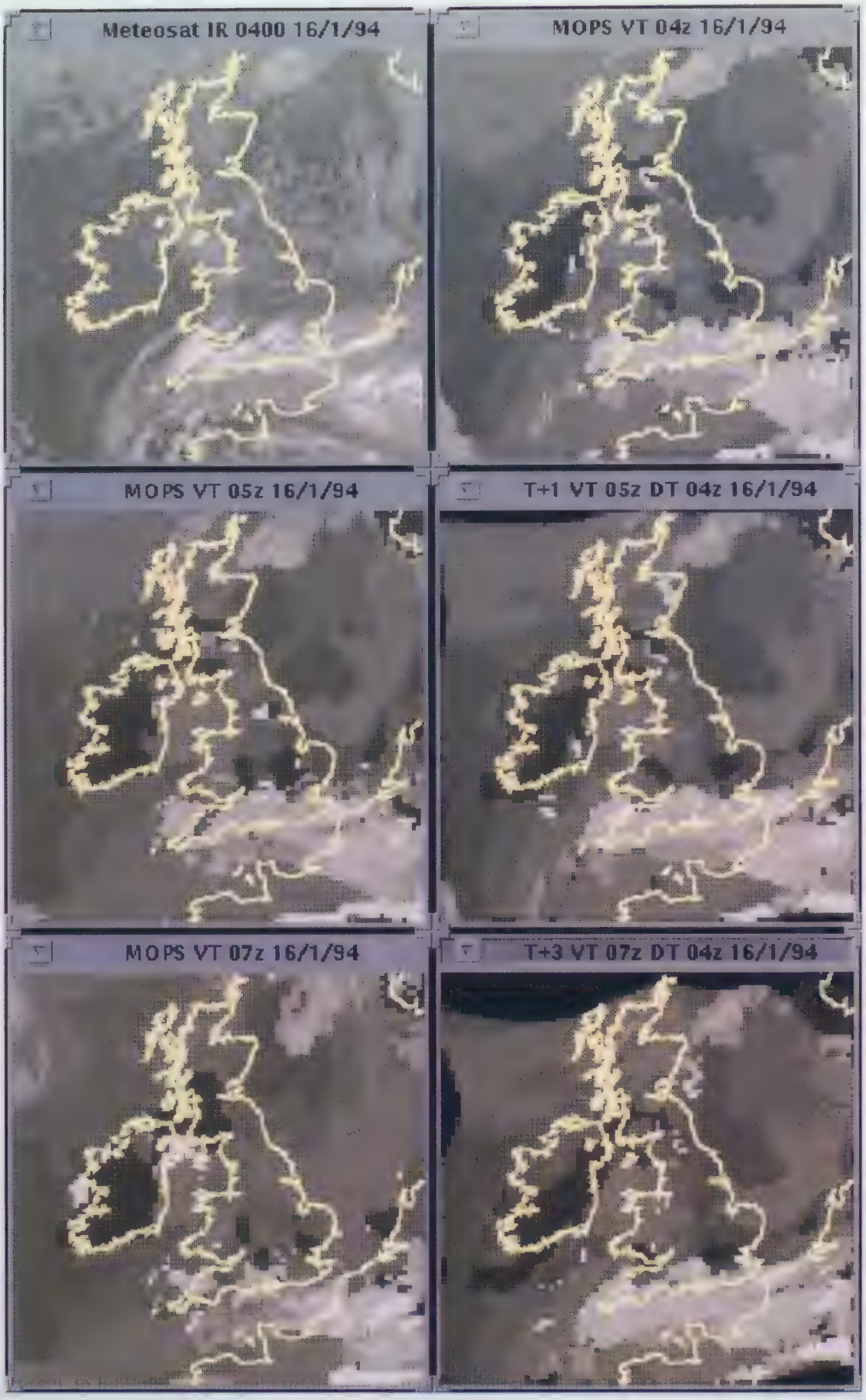
T+3 VT 07z DT 04z 7/12/93

Figure 5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MOPS VT 05z 16/1/94
T+1 VT 05z DT 04z 16/1/94
MOPS VT 07z 16/1/94
T+3 VT 07z DT 04z 16/1/94

Figure 6

Meteosat IR 1400 16/1/94
MOPS VT 14z 16/1/94
MOPS VT 15z 16/1/94
T+1 VT 15z DT 14z 16/1/94
MOPS VT 17z 16/1/94
T+3 VT 17z DT 14z 16/1/94

Figure 7

Meteosat IR 0800 25/1/94
MOPS VT 08z 25/1/94
MOPS VT 09z 25/1/94
T+1 VT 09z DT 08z 25/1/94
MOPS VT 11z 25/1/94
T+3 VT 11z DT 08z 25/1/94

Figure 8

Meteosat IR 1600 25/1/94
MOPS VT 16z 25/1/94
MOPS VT 17z 25/1/94
T+1 VT 17z DT 16z 25/1/94
MOPS VT 19z 25/1/94
T+3 VT 19z DT 16z 25/1/94

Figure 9

Figure 3